REMARKS

This Amendment is responsive to the First Office Action on the merits of March 2, 2004. Entry of the following amendments and reconsideration and allowance of claims 1-28 as set forth herein is respectfully requested.

The Status of the Application

The status of the claims as set forth in the March 2, 2004 Office Action is as follows:

Claims 1-28 stand rejected under 35 U.S.C. § 103(a) as being unpatentable over Yim, U.S. published application no. 2003/0031351 A1 (hereinafter, Yim '351) in view of Yim et al. U.S. published application no. 2002/0136440 A1 (hereinafter, Yim et al. '440)

Applicants request consideration of the Information Disclosure Statement submitted with this Amendment

A 37 CFR 1.97(c) Information Disclosure Statement is submitted herewith, along with the appropriate fee set forth in 37 C.F.R. §§ 1.17(p). Accordingly, Applicants request consideration of the references in this Information Disclosure Statement.

The Specification has been amended to address the Drawing Objection

As pointed out in the Office Action, FIGURE 13 shows four (not five) isolated vessels **332** as well as one pair of overlapping vessels **334**. The specification has been amended at the FIGURE 13 caption and at page 27 to indicate four (not five) isolated vessels **332**. Applicants respectfully submit that these amendments to the specification obviate the drawing objection.

The Present Application

In typical localized vessel tracking methods, vessel tracking proceeds locally from one voxel to a neighboring (or near-neighboring) voxel in an iterative fashion. Such a localized tracking approach is generally not robust: for example, it can fail at vessel overlaps by switching the tracking to the crossing vessel, or can fail at

bifurcations by failing to identify and follow both branches of a bifurcation or other vessel juncture.

The present application addresses these problems by initially globally identifying vessel centers throughout the three-dimensional image, and then performing vessel tracking using that global information. FIGURE 6A, for example, diagrammatically illustrates dividing the image volume by spaced apart planar slices and globally identifying vessel centers in each of the planar slices. The vessel centers in each plane are identified by recursive erosion including flood-filling the vascular structures and then eroding the flood-filled areas to identify vessel centers. This technique readily identifies vessel overlaps and bifurcations as tubular vessel structures having more than one center (see, for example, FIGURES 18A-D), and these are tagged. Alternatively, a radial line, center likelihood measure, or other technique can be used to identify the vessel centers. With vessel centers and overlaps and furcations identified globally, vessel tracking is performed by finding a vessel direction, vessel plane, and vessel boundaries for each vessel center, taking advantage of the global vessel centers information to ensure that all branches and overlapping vessels are appropriately incorporated into the tracked vascular system.

Another issue with existing tracking techniques is that they are typically not readily applied to black blood angiographic data. In the case of white blood data, the vascular areas are bright compared with the image background. Hence, vascular areas are distinguishable from dark features such as bone linings, air pockets, and muscle tissues. Black blood angiography has certain advantages, such as providing improved vessel lumen definition. However, black blood data shows the vascular regions at low intensity, and so the vascular data can be confused with other dark features of the magnetic resonance images.

The present methods apply to black blood angiographic data by inverting the intensity scale. As seen in FIGURE 8, for example, the black blood angiographic data is processed by masking out the non-vascular black regions, such as bone, air, and muscle regions, to produce an image principally containing black blood regions and gray tissue regions. This black blood/gray tissue image is intensity-inverted to create a "pseudo-white blood" angiographic volume, which is subsequently processed similarly to processing of white blood data.

Additionally, because a significant advantage of black blood angiography is improved vessel lumen definition as compared with white blood imaging (e.g., p. 7 lines 24-28), in yet another aspect the present application ensures vessel lumens are well-defined by using a level set framework optimization of a geometric contour. At tagged vessel overlaps and furcations, a geometric contour is placed around each vessel center and the contour optimization is performed simultaneously for both vessels. This approach has been applied previously in brain tissue segmentation applications; however, for vascular boundary estimation other techniques such as parametric contour methods have been employed, which have difficulty at sharp boundary features and suffer from bleed-through. See p. 37 lines 5-13.

The Yim references

Yim '351 is directed toward ordered region growing (ORG) techniques for vessel tracking. Starting at a given seed or point, a region having a boundary around that point is analyzed and the highest intensity boundary point is defined as the new center point. The region/boundary defining and highest intensity point selection is repeated at the new center point, and thus the vessel is grown.

Yim '351 does not disclose a method for globally identifying vessel centers. Rather, Yim '351 is a localized tracking method. Improved tracking is obtained by (i) having the user select several distal endpoints for the tracking to reach (see ¶[0080]); or (ii) trimming off smaller vessels to retain only the larger vessels (see ¶[0084]). Yim '351 does not disclose geometric contour optimization to define vessel boundaries, much less contour optimization in a level set framework. Still further, Yim '351 does not address the issue of extraneous low intensity contrast from bones, air, and muscle in analysis of black blood angiographic data.

Yim et al. '440 is directed toward modeling the lumen of a <u>single</u> blood vessel, with primary interest in modeling the lumen at a stenosis. A user selects the vessel axis (see ¶[0041]) and a tube is defined along the axis. The tube is deformed and fitted to the vessel edges in the image. Gradient operations are applied, apparently to provide edge-enhancement in the image. Since Yim et al. '440 is directed toward modeling major vessels, there will be few if any bifurcations. Accordingly, a bifurcation, if present, is dealt with using two overlapping tubes, as shown in

FIGURES 8 and 9. The tube deformation involves contour optimization in three dimensions, but does not appear to employ a level set framework.

Yim et al. '440 is not directed toward tracking a vascular system, but rather toward accurately modeling the lumen of a single large vessel or bifurcated vessel, such as a vessel having a stenosis. Accordingly, Yim et al. '440 dies not disclose globally identifying vessel centers in an image. There is no discussion of the issue of extraneous low intensity contrast from bones, air, and muscle in analysis of black blood angiographic data.

Applicants ask for reconsideration of claims 8-11, 26, and 27

Claim 8 calls for flood-filling imaged vascular structures to form filled regions defined by pixels having a first value, and iteratively eroding the edges of the filled regions to identify vessel center points. **Claim 26** calls for flood-filling means and iterative eroding means for performing these functions.

The Office Action identifies the singular reference to a "watershed method" in Yim et al. '440 ¶[0007] as corresponding to the limitations of flood-filling the vascular edges to form filled regions defined by pixels of a first value, and identifying vessel centers through iterative removal of pixels having the first value from around the edges of the filled regions.

Yim et al. '440 ¶[0007] reads is as follows (underscore added):

> Surface reconstruction of vessels has also been obtained from segmentation methods. Segmentation methods incorporate spatial and intensity criteria to objectively classify regions or voxels in an image. For example, a k-means clustering method automatically identifies voxels within vessels from MRA. This method compensates for the partial volume effect that diminishes the intensity of the smaller vessels thus causing errors for methods based on image intensity alone. <u>Another method uses "fuzzy connectivity" for separating arteries and veins in MRA obtained with blood pool contrast agents. The arteries and veins are separated from the arteries based on a limited number of seed points inside and outside of the vessels. A similar watershed method has been successfully applied to MRA of the thoracic aorta</u>.

The context suggests that "watershed method" is essentially a method using "fuzzy connectivity" for separating types of regions (i.e., arteries and veins) based on a limited number of seed points inside and outside of the regions. To ascertain what is the correct meaning, Applicants located Wust et al., Phys. Med. Biol. **43**, pp.

3295-3307 (1998), which is included in the IDS submitted with this Amendment. Wust p. 3299 describes a "watershed transformation" in which an edge-enhancing gradient is applied to the image, and the large gradients at the boundaries of regions define ridges/watersheds between regions. Regions within each watershed are then classified based on a selectable criterion such as mean value, median, variance, etc. This description is completely consistent with the context of "watershed method" as used at Yim et al. '440 ¶[0007], where the "selectable criterion" is based on the seed points inside and outside of the vessel.

Applicants do not see how the term "watershed method" fairly suggests flood-filling the vascular edges and iteratively removing pixels having the first value from around the edges of the filled regions to identify a vessel center. Indeed, the watershed method does not appear to be a method for identifying centers of regions at all; rather, it appears to be a method for classifying regions.

Accordingly, it is respectfully submitted that claims 8-11, 26, and 27 patentably distinguish over the references of record. Applicants therefore ask for reconsideration and allowance of claims 8-11, 26, and 27.

Claims 1-4 and 7 as set forth herein patentably distinguish over the references of record

Claim 1 calls for flood-filling and iterative removal of pixels similarly to claim 8. Accordingly, the comments pertaining to claim 8 pertain to claim 1 as well.

Claim 1 further calls for the vessel centers to be identified in slices spanning the angiographic image representation, so that the vessel centers are representative of a three-dimensional vascular structure. The processor of claim 1 further segments, tracks, extracts, enhances, or identifies information about the three-dimensional vascular structure using the identified vessel centers as operative inputs.

Neither Yim reference calls for identifying vessel centers in slices spanning a three-dimensional image. Yim '351 has the user identify endpoints of vessels. There is no suggestion that the user-selected endpoints span a three-dimensional image so as to be representative of the vascular system. Yim et al. '440 is directed toward fitting the lumen of a single vessel, and does not address identifying vessel centers, much less identifying vessel centers in three dimensions that are representative of the vascular system.

Claim 2 calls for inverting the intensities of the image elements to generate an intensity-inverted image in the case where the vascular contrast includes black blood vascular contrast. The subject matter of claim 2 is not specifically addressed in the Office Action, and Applicants find no disclosure or suggestion in the Yim references to perform this conversion.

Accordingly, it is respectfully submitted that claims 1-4 and 7 patentably distinguish over the references of record. Applicants therefore ask for reconsideration and allowance of claims 1-4 and 7.

Claims 5 and 6 as set forth herein patentably distinguish over the references of record

Claim 5 has been placed into independent form, and calls for, among other aspects, flood-filling the vascular edges to form filled regions defined by pixels having a first value, identifying vessel centers through iterative removal of pixels having the first value from around the edges of the filled regions, and tagging vessel overlaps and vessel furcations identified as a plurality of vessel centers corresponding to a single filled region.

Yim et al. '440 deals with a bifurcation by using two overlapping tubes, as shown in FIGURES 8 and 9. There is no suggestion of tagging vessel overlaps and furcations identified as a plurality of vessel centers corresponding to a single filled region, as called for in claim 5. Yim '351 does not disclose or fairly suggest tagging vessel overlaps or furcations. Rather, Yim '351 discloses a region growing method that apparently addresses furcations by growing along both branches. Indeed, Yim '351 specifically notes that directionally based vessel tracking typically requires user interaction to cope with vessel furcations (Yim '351, last line of ¶[0027]).

In contrast, claim 5 addresses furcations by calling for tagging furcations identified as a plurality of vessel centers corresponding to a single filled region, and by calling for performing the tracking using the identified vessel centers as operative inputs.

Claim 6 specifies that the tracking uses the identified vessel centers by connecting the vessel centers and vessel edges associated therewith starting at the vessel furcations to form segmented vessel trees including vessel furcations. This approach is not disclosed or fairly suggested by the Yim references.

Accordingly, it is respectfully submitted that claims 5 and 6 patentably distinguish over the references of record. Applicants therefore ask for allowance of claims 5 and 6.

Applicants ask for reconsideration of claims 18-25 and 28

Claim 18 calls for identifying a plurality of vessel centers in three dimensions that are representative of the vascular system, selecting a first vessel center, finding a first vessel direction corresponding to the local direction of the vessel at the first vessel center, defining a first slice that is orthogonal to the first vessel direction and includes the first vessel center, estimating vessel boundaries in the first slice by iteratively propagating a closed geometric contour arranged about the first vessel center, repeating the selecting, finding, defining, and estimating for the plurality of vessel centers; and interpolating the estimated vessel boundaries to form a vascular tree. **Claim 28** calls for an apparatus including means for performing these functions.

Neither Yim reference identifies a plurality of vessel centers in three dimensions that are representative of the vascular system. Yim '351 has the user identify endpoints of vessels. These endpoints are not intended to be representative of the vascular system; rather, they are selected to identify a termination point for vessel tracking. Yim et al. '440 is directed toward fitting the lumen of a single vessel with a tube, and does not identify vessel centers, much less vessel centers in three dimensions that are representative of the vascular system.

Neither Yim reference discloses or fairly suggests forming a vascular tree by interpolating the estimated vessel boundaries estimated around each of a plurality of vessel centers in three dimensions that are representative of the vascular system. This approach allows tracking of complex, branching three-dimensional vascular systems by ensuring that the vessels and vessel branches are accounted for through the use of the plurality of vessel centers in three dimensions that are representative of the vascular system.

In addition, Applicants note that many limitations contained in the dependent claims 19-25 have not been specifically addressed in the Office Action. For example, claim 19 specifies certain geometric contour propagation constraints. Claim 21 calls out a specific method for finding a vessel direction. Claims 22-25 call out specific

methods for finding vessel centers. These and other subject matter of dependent claims 19-25 are not specifically addressed in the Office Action.

Accordingly, it is respectfully submitted that claims 18-25 and 28 patentably distinguish over the references of record. Applicants therefore ask for reconsideration and allowance of claims 18-25 and 28.

Claims 12-17 as set forth herein patentably distinguish over the references of record

Claim 12 has been placed into independent form as a processor claim for carrying out a vascular system characterization method. The method includes flood-filling and iterative eroding to identify vessel centers, and additionally includes vessel tracking based on the vessel centers performed by iteratively finding the vessel direction at a vessel center, and estimating vessel boundaries around the vessel center by iterative propagation of a closed geometric contour.

As discussed previously, the "watershed method" of Yim et al. '440 ¶[0007] relates to classifying types of regions (i.e., arteries and veins) based on a limited number of seed points inside and outside of the regions. It does not relate to identifying vessel centers by flood-filling and iterative eroding, as called for in claim 12. Moreover, neither Yim reference discloses or fairly suggests identifying a plurality of vessel center points representative of the vascular system for use in vessel tracking.

In addition, Applicants note that substantial subject matter contained in the claims depending from claim 12 have not been specifically addressed in the Office Action. For example, claims 13-15 call for a level set framework contour optimization. Claim 16 calls for a two-pass erosion process. Claim 17 calls for intensity inversion in the case of black blood angiographic data. These and other subject matter of dependent claims 13-17 are not specifically addressed in the Office Action.

Accordingly, it is respectfully submitted that claims 12-17 patentably distinguish over the references of record. Applicants therefore ask for reconsideration and allowance of claims 12-17.

CONCLUSION

Based on the foregoing, it is submitted that claims 1-28 patentably distinguish over the references of record. Accordingly, reconsideration and allowance of claims 1-28 is earnestly requested.

Respectfully submitted,

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